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(54) SEMICONDUCTOR DEVICE

(71) We, PHILIPS ELECTRONIC AND ASSOCIATED INDUSTRIES LIMITED, of Abacus House, 33 Gutter Lane, London, E.C.2., a British Company, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:

The invention relates to a semiconductor device comprising a semiconductor body having semiconductor zones of a transistor adjoining a surface of the body, said transistor having an emitter contact which contacts only a single emitter zone of the transistor, said emitter zone being a semiconductor surface zone which in the semiconductor body is surrounded by the base zone, said base zone extending from the surface in the collector zone, a part of said collector zone having a lower resistivity than another part, the high resistivity part extending at least partly between the base zone and the low resistivity part and the low resistivity part being present at least below the whole base zone.

As is known, planar bipolar transistors are used, for example, in integrated circuits in which the collector zone is formed by a comparatively high resistivity isolated region or island; in order to reduce the collector series resistance in said island, a comparatively low resistivity part in the form of a buried layer is provided below the base zone at some distance from said base zone.

Such transistors are often operated in saturation, for example, when they are used as electronic switches as is the case in many logic circuits. It is then *inter alia* of importance that in the conductive condition of the switch the series resistance be as small as possible. Transistors for said use therefore preferably have a low saturation voltage or knee voltage.

According to the invention there is provided a semiconductor device comprising a semiconductor body having semiconductor zones of a transistor adjoining a surface of the body, said transistor having an emitter contact which contacts only a single emitter zone of the transistor, said emitter zone being a semiconductor surface zone which in the semiconductor body is surrounded by the base zone, said base zone extending from the surface in the collector zone, a part of said collector zone having a lower resistivity than another part, the high resistivity part extending at least partly between the base zone and the low resistivity part, and the low resistivity part being present at least below the whole base zone, and the emitter zone extending in a portion of the base zone which is entirely surrounded at the surface by an adjoining thicker portion of the base zone, which thicker portion reaches from the surface at least down to the low resistivity part of the collector zone.

Such a transistor can have a comparatively low saturation voltage.

Such a semiconductor device may be constructed as a single circuit element in which the semiconductor body is formed, for example, by a low resistivity substrate on which an epitaxial layer of the same conductivity type but having a higher resistivity is provided. Preferably, however, the transistor forms part of an integrated circuit in which the collector zone consists of a surface region which is electrically separated from a remaining part of the semiconductor body and in which at the surface the base zone and the emitter zone are provided, the low resistivity part of the collector zone being constructed as a buried layer.

The collector zone may be separated and, at least during operation, be isolated electrically from the remaining part of the semiconductor body in known manner by means of *p-n* junctions and/or grooves and/or insulating material.

In a preferred form of such a semiconductor device the surface region forming the collector zone is electrically separated from the remaining part of the semiconductor body in a lateral direction by a surface-adjoining separation zone of a conductivity type opposite to that of the collector zone, which separation zone and the thicker portion of the base zone have substantially the same surface concentration and, in a direction transverse to the surface, substantially the same variation of the doping concentration with the distance to the surface.

In this manner the thicker portion of the base zone can be obtained simultaneously with the doping operation necessary for the electric isolation of the circuit elements, so that no extra operations need be introduced in the manufacturing process.

A surface zone of the same conductivity type but having a higher doping concentration (i.e. a low resistivity) is preferably present in the collector zone, said surface zone adjoining the base zone at the surface and preferably surrounding the base zone as much as possible.

It can be further advantageous for the emitter zone at the surface to cover the whole thinner portion of the base zone present within the thicker portion. As will be explained hereinafter, this structure can be manufactured in a comparatively simple manner.

A conductive contact to the base zone is preferably provided on the thicker portion of the base zone, the contact surface between said contact and the base zone being present entirely within said thicker portion.

Embodiments of the invention will now be described, by way of example, with reference to the accompanying drawing, in which:—

Fig. 1 is a diagrammatic plan view of a first semiconductor device in accordance with the invention;

Fig. 2 is a diagrammatic cross-sectional view of said first device and taken on the line II-II of Fig. 1, and

Fig. 3 is a diagrammatic cross-sectional view of a second semiconductor device in accordance with the invention.

The semiconductor device shown in Figs. 1 and 2 has a semiconductor body 1 a surface 2 of which the semiconductor zones 3, 4 and 5 of a transistor adjoin. The base zone 4 is a surface zone which extends from the surface 2 in the collector zone 5 and which surrounds in the semiconductor body a single emitter zone adjoining the surface 2. Part of the collector zone 5 is formed by the substrate *5a* and has a lower resistivity than the part *5b* formed by an epitaxial layer provided on the substrate and having the same conductivity type as the substrate but a lower doping concentration. The high resistivity part *5b* is present at least partly between the base zone 4 and the low resistivity part *5a*, while the low resistivity part *5a* extends below the whole base zone 4.

In accordance with the invention, the base zone 4 has a portion *4a* in which the emitter zone 3 extends and an adjoining thicker portion *4b* which surrounds the thin portion *4a* entirely at the surface and which from the surface 2 reaches at least down to the low resistivity part *5a* of the collector zone 5. It has been found that by arranging the thick portion *4b* of the base zone to be annular, at least with a closed geometry, around the emitter zone 3 and causing said portion *4b* to adjoin moreover the low resistivity part *5a* of the collector zone 5, a considerable reduction of the saturation voltage or knee voltage of the transistor is achieved. In this case it is of particular importance that the thick portion *4b* of the base zone should form a closed region which surrounds the emitter zone entirely. The part of the high resistivity portion *5b* of the collector zone adjoining the thin portion *4a* of the base zone below the emitter zone 3 is then fully enclosed within the base zone 4 and the low resistivity part *5a* of the collector zone.

A further reduction of the saturation voltage of said transistor can be achieved by providing in the high resistivity portion *5b* of the collector zone a more highly-doped (low-resistivity) zone *5c* which adjoins the base zone 4 at the surface 2 and which surrounds the base zone 4 as much as possible and preferably entirely.

An insulating layer 6 is present on the semiconductor surface and has apertures through which the emitter zone 3 and the base zone 4 can be connected to a conductive contact (not shown). The emitter zone 3 is provided with its own conductive contact, that is to say a contact by means of which said emitter zone during operation can be used independently of possible similar zones belonging to the transistor and can be connected in a circuit. The contact surface between the base zone 4 and the conductive contact connected therewith which contact surface area is determined by the aperture present above the base zone 4 is entirely present within the thick portion *4b* of the base zone. In this manner the thin portion *4a* remains available entirely as an active base zone. The collector zone may be provided, for example, with a conductive contact on the lower side of the semiconductor body 1. Such a connection is denoted diagrammatically by reference 8 in Fig. 2.

The semiconductor device shown in Fig. 3 is an integrated circuit having a semiconductor substrate 11 of one conductivity type which is provided with a surface layer

12 of the opposite conductivity type. Parts 13 and 14 of said surface layer 12 are separated laterally from each other and from the remaining part of the surface layer by means of separation zones 15 of the one conductivity type which extend from the surface 16 through the layer 12 down to or down into the substrate 11.

A transistor is provided in each of the isolated regions or islands 13 and 14 separated from the remaining part of the semiconductor body. For said purpose, said islands each have a buried layer 17 of said opposite conductivity type which is present at the boundary between the substrate 11 and the surface layer 12. The island 14 comprises a transistor of a conventional structure having a collector zone 14 which is provided with a buried layer 17 and a deep contact zone 18 which extends from the surface 16 down to the buried layer and which both serve to reduce the collector-series resistance and furthermore a base zone 19 of a substantially uniform depth of penetration and an emitter zone 20.

The integrated circuit described so far with the transistor present in the island 14 can be manufactured entirely in a manner conventionally used in semiconductor technology and with the conventional photoetching, masking and doping methods. An important advantage of the present invention is that with the same manufacturing process and without the introduction of extra operations, transistors having a relatively low saturation voltage can also be incorporated. Such a transistor is present in the island 13 which forms the collector zone and which is provided with a buried layer 17 like the island 14. Simultaneously with the provision of the separation zones 15, an annular zone 24*b* is provided in the island 13 which, *inter alia* due to the comparatively high doping concentration of the buried layer 17, does not reach down into the substrate 11 but terminates on the buried layer 17 and forms a (part of a) *p-n* junction 21*a* therewith. The zone 24*b* provided in this manner will have substantially the same surface doping concentration, and (in a direction transverse to the surface) substantially the same variation of the doping concentration with the distance to the surface. The annular, at least closed, zone 24*b* has an aperture in which the thin portion 24*a* of the base zone 24 can be provided simultaneously with the base zone 19. No accurate masking for the zone 24*a* need be provided. The aperture in the masking layer through which the doping is provided need only be larger on all sides than the aperture in the zone 24*b* present within said aperture. The edge of the aperture in the masking layer preferably coincides approximately with the outer boundary 21*b* of the zone 24*b*. No accurate alignment treatment need be carried out either for the emitter zone 23 which can be provided simultaneously with the zone 20. The emitter zone 23 may cover the thin portion 24*a* of the base zone entirely at the surface and may reach to or into the thick portion 24*b* in the lateral direction. During operation the injection of charge carriers from the emitter zone 23 will take place substantially entirely *via* the part of the emitter-base junction which adjoins the thin portion 24*a* of the base zone and is present at a comparatively short distance from the base-collector junction, in particular with the low currents and voltages for which the transistor is in particular suitable.

The transistor having a low saturation voltage is intended in particular for use at low voltages and currents and therefore preferably has only a single emitter zone. For completeness' sake it is to be noted, however, that for special uses, for example in a long-tailed pair, a second zone of the same conductivity type may be provided simultaneously with the emitter zone 23. Said second zone may be provided together with the zone 23 in the same thin base portion 24*a* or in a second thin base portion which is separated therefrom and which in turn is also surrounded by the thick portion 24*b*. The second zone has its own conductive electric connection separated from that of the first emitter zone 23 and may either be used as a second independent emitter zone or may serve as a collector zone of a lateral transistor formed by the emitter zone 23, the base zone 24 and the said second zone.

Simultaneously with the collector zone 18, a more highly doped (low resistivity) zone 26 belonging to the collector zone 13 may be provided around the thick portion 24*b* of the base zone. It will be obvious that, although the deep zones 18 and 26 are particularly favourable with a view to the collector series resistance of the transistors and the deep zone 26 moreover has a favourable influence on the inverse current amplification factor and hence on the saturation voltage of the transistor in the island 13, shallower zones may also be used instead of said zones, and be provided, for example, simultaneously with the emitter zones. As a result of this the manufacturing process can be simplified by saving a doping operation and/or space can be saved at the semiconductor surface. Such a slightly simplified transistor structure also provides a considerable reduction of the saturation voltage. Whereas for a transistor of the conventional structure, for example, a saturation voltage of approximately 70 mV was measured, for a transistor of the described new structure provided simultaneously the saturation voltage in otherwise the same conditions was only approximately 14 mV.

An insulating layer 27 is present on the semiconductor surface 16 in which in the usual manner by means of a pattern of conductor tracks 28 and *via* apertures in the insulating layer 27, electric contacts and connections can be obtained in the desired places. The lower side of the substrate 11 may also be provided with an electric connection.

Thus, there is provided a semiconductor device having a transistor which is simple to fabricate and has a very low saturation voltage in which during operation transistor action occurs substantially only in the region determined by the thin base portion 24*a*, whereas, when the collector zone serves as an emitter zone, the injection of charge carriers is substantially entirely restricted to the part 21*c* of the base-collector junction 21 present below the emitter zone 23.

Such a semiconductor device in accordance with the invention is particularly suitable for use at low currents and voltages such as in battery-operated circuits. The slightly reduced collector-base breakdown voltage will be no objection either in circuits of this type. Moreover, for example, in circuits for clockworks, the memory function of the comparatively large base-collector capacitance may effectively be used.

It will be obvious that many variations are possible to those skilled in the art without departing from the scope of this invention. For example, the transistor with low saturation voltage may also form part of integrated circuits in which other known isolation methods have been used for the mutual separation of the circuit elements. For example, the isolation zones 15 in Fig. 3 may be replaced entirely or partly by grooves and/or by insulating material. As is known insulating layers which are sunk entirely or partly in the semiconductor body and which can be obtained, for example, by local oxidation may *inter alia* be used for this purpose. The more highly doped zones 5*c* and 26 which counteract the injection over the outer upright edge of the thick base portions 4*b* and 26, respectively, may also be replaced by a groove and/or by insulating material.

WHAT WE CLAIM IS:—

1. A semiconductor device comprising a semiconductor body having semiconductor zones of a transistor adjoining a surface of the body, said transistor having an emitter contact which contacts only a single emitter zone of the transistor, said emitter zone being a semiconductor surface zone which in the semiconductor body is surrounded by the base zone, said base zone extending from the surface in the collector zone, a part of said collector zone having a lower resistivity than another part, the high resistivity part extending at least partly between the base zone and the low resistivity part, and the low resistivity part being present at least below the whole base zone, and the emitter zone extending in a portion of the base zone which is entirely surrounded at the surface by an adjoining thicker portion of the base zone, which thicker portion reaches from the surface at least down to the low resistivity part of the collector zone.

2. A semiconductor device as claimed in Claim 1, in which the transistor forms part of an integrated circuit, and the collector zone consists of a surface region which is electrically separated from a remaining part of the semiconductor body and in which at the surface the base zone and the emitter zone are provided, the low resistivity part of the collector zone being constructed as a buried zone.

3. A semiconductor device as claimed in Claim 2, in which the surface region forming the collector zone is electrically separated from the remaining part of the semiconductor body in a lateral direction by a surface-adjoining separation zone of a conductivity type opposite to that of the collector zone, which separation zone and the thicker portion of the base zone have substantially the same surface doping concentration and, in a direction transverse to the surface, substantially the same variation of the doping concentration with the distance to the surface.

4. A semiconductor device as claimed in any of the preceding Claims, in which the base zone is provided at the surface with a conductive contact in which the contact surface area between the base zone and said contact is present entirely within the thicker portion of the base zone.

5. A semiconductor device as claimed in any of the preceding Claims, in which the base zone is surrounded entirely at the surface by a low resistivity part of the collector zone, which low resistivity part adjoins the base zone.

6. A semiconductor device as claimed in any of the preceding Claims, in which the emitter zone at the surface covers the whole thinner portion of the base zone.

7. A semiconductor device substantially as described with reference to Figures 1 and 2 of the accompanying drawing.

8. A semiconductor device substantially as described with reference to Figure 3 of the accompanying drawing.

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1 480 050 COMPLETE SPECIFICATION
1 SHEET This drawing is a reproduction of the Original on a reduced scale.

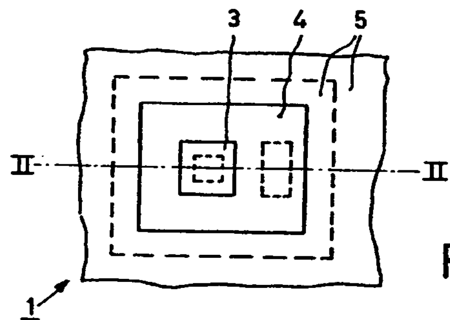

Fig.1

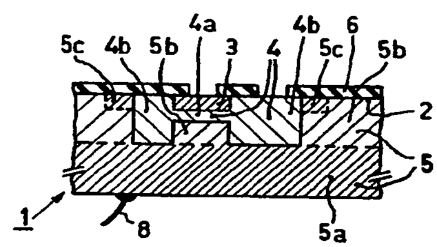

Fig.2

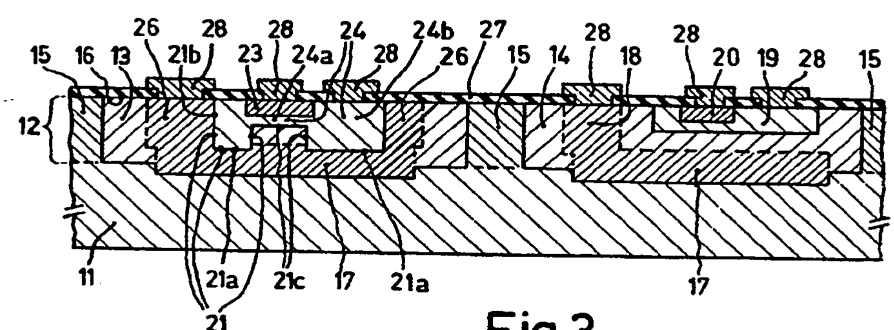

Fig.3